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TESTS OF OXYACETYLENE WELDED JOINTS IN STEEL PLATES

BY

HERBERT F. MOORE

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UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

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BY
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TESTS OF OXYACETYLENE WELDED JOINTS IN STEEL PLATES

1. *Introduction.*—This bulletin gives the results of a series of tests of the strength of oxyacetylene welded joints in mild steel plates. The joints were welded by skilled workmen in a plant especially equipped for oxyacetylene welding.

Bulletin No. 45 of the University of Illinois Engineering Experiment Station, "The Strength of Oxyacetylene Welds in Steel," by Herbert L. Whittemore, gives the results of tests of strength of welds made under repair shop conditions; it also gives a detailed discussion of the technique of welding with the oxyacetylene blow torch.

2. *Acknowledgment.*—The plates were furnished by the Oxweld Acetylene Company, and the welding was done by them at their Chicago plant. The tests of static strength of welds were made by Messrs. G. W. Watts and E. A. Brown of the class of 1915 of the College of Engineering of the University of Illinois. Messrs. Brown and Watts also acted as inspectors during the welding of the test plates. Director B. W. Benedict of the University of Illinois shop laboratories coöperated with the writer in the general planning of the tests. The tests were all made in the laboratory of applied mechanics of the University of Illinois.

3. *Tests and Test Pieces.*—Tests were made under three conditions of loading: (*a*) static load in tension (in a testing machine), (*b*) repeated load (bending), and (*c*) impact in tension (in a drop testing machine).

The static tension tests give an index of the resistance of the welded joint to loads applied only a few times and without heavy impact, such as floor loads in warehouses and the dead loads on bridges. The repeated stress tests give an indication of the resisting power of the welded joint to loads repeatedly applied, such as loads carried by springs and carriage axles. The impact tests give an index of the ability of the welded joints to resist sudden heavy shock without complete rupture. High resistance to rupture under impact represents insurance against the sudden and complete failure of a part subjected to severe bending or stretching, rather than its stress-carrying ability. High resistance to rupture under impact is of importance in material for machine parts or for railway service.

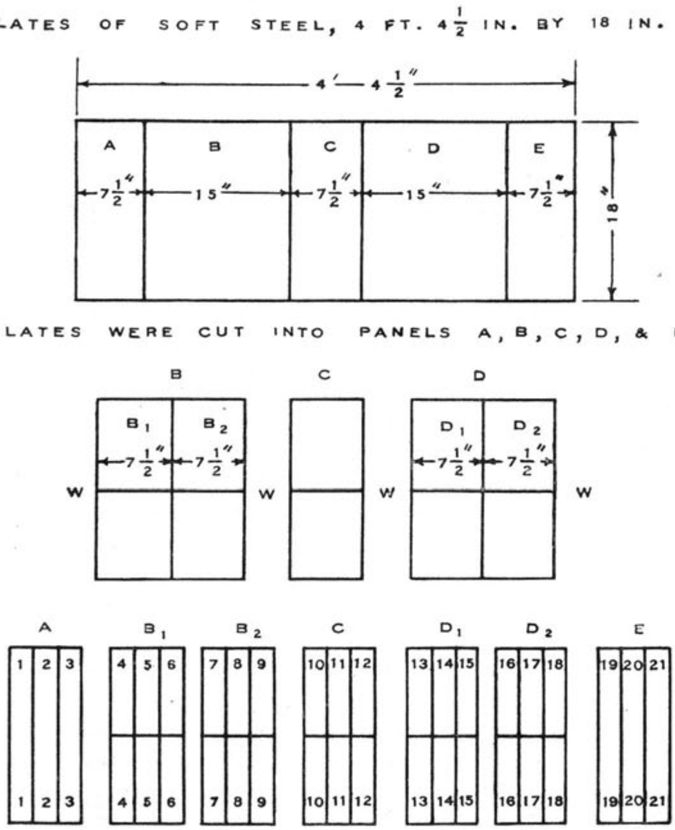

Fig. 1. Plan of Welding and Cutting Test Plates and Panels

The plates in which the test joints were made were of steel with a carbon content of about 0.16 per cent. The following thicknesses of plate were used: No. 10 gauge, ¼ in., ½ in., ¾ in., and 1 in. In all, eleven plates were furnished, three ½-in. plates, and two each of No. 10 gauge, ¼-in., ¾-in., and 1-in. Fig. 1 shows the plan of welding and cutting a test plate into test panels for varying heat treatment, and also the plan of cutting these test panels into test strips to form individual test pieces. The welding of the test panels was done in the presence of inspectors from the University of Illinois, and these inspectors stamped each test strip with an identifying mark before it was cut from the test panel. The approximate speeds of welding for the various thicknesses of plate were as follows: No. 10 gauge,

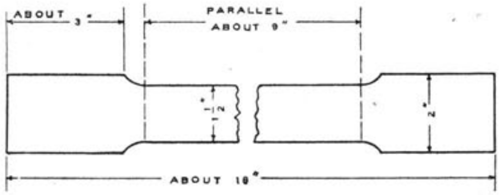

Fig. 2. Tension Specimen

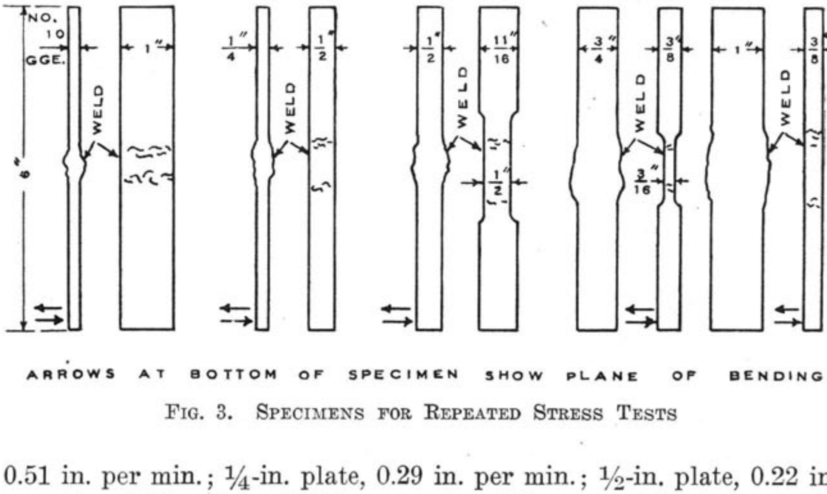

Fig. 3. Specimens for Repeated Stress Tests

0.51 in. per min.; ¼-in. plate, 0.29 in. per min.; ½-in. plate, 0.22 in. per min.; ¾-in. plate, 0.13 in. per min.; 1-in. plate, 0.11 in. per min.

The shape and size of the various test pieces cut from the test strip are shown in Figs. 2, 3, and 4. Fig. 2 shows the static tension test pieces, Fig. 3 shows the test pieces for the repeated stress tests, and Fig. 4 shows the test pieces for impact tests.

Nearly all tests were run in triplicate. There were 104 tension test specimens, 106 repeated stress specimens, and 58 impact specimens tested.

4. *Apparatus.*—The tension tests for static strength were made in a 100,000-lb. Riehle testing machine fitted with an autographic apparatus for drawing load-stretch diagrams. This apparatus was not of sufficient delicacy to permit the measurement of small elastic stretches, but did measure the comparatively large plastic stretches beyond the yield point, and did permit a good determination of the yield point to be made. The location of the yield point is plainly shown by the "knee" of the load-stretch diagram. Fig. 5 shows typical diagrams for static tests.

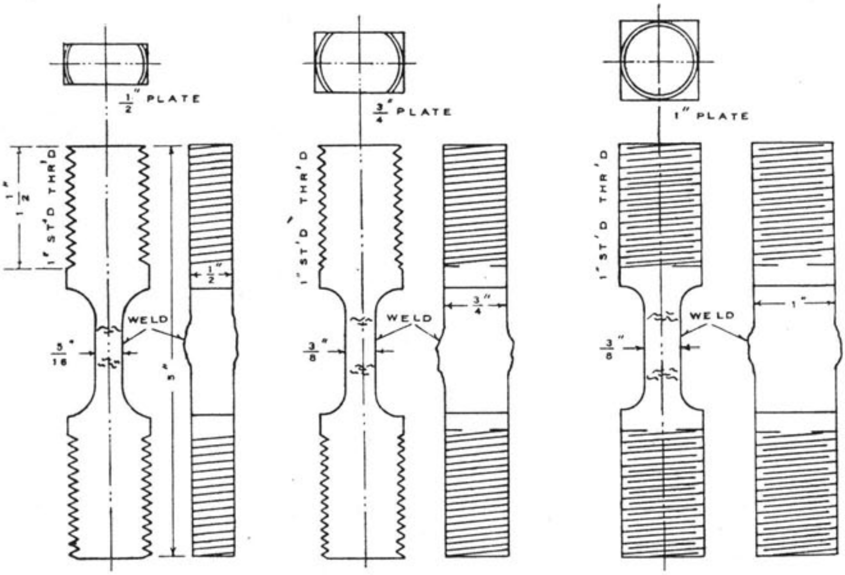

FIG. 4. SPECIMENS FOR IMPACT TESTS

The repeated stress tests were made in an Upton-Lewis endurance testing machine. Fig. 8 shows this machine. A crank *C*, with adjustable throw is driven by a motor or other source of power, and actuates a connecting rod, *D*, which, in turn, causes one end of the specimen, *Sp*, to vibrate back and forth. The specimen is held in a vise, *V*, which is pivoted at *O*; the swing of the vise round this pivot is resisted by the calibrated springs, *S*. These springs set up bending stress in the specimen. The bending moment is proportional to the width of the diagram drawn by the pencil, *R*. The pencil, *R*, draws a diagram on a strip of paper which is moved a very short distance for each revolution of the crank, C. Fig. 9 shows a typical diagram from the machine. The width of each diagram is a measure of the bending stress in the specimen, and the length of each diagram is a measure of the number of repetitions of bending stress required to

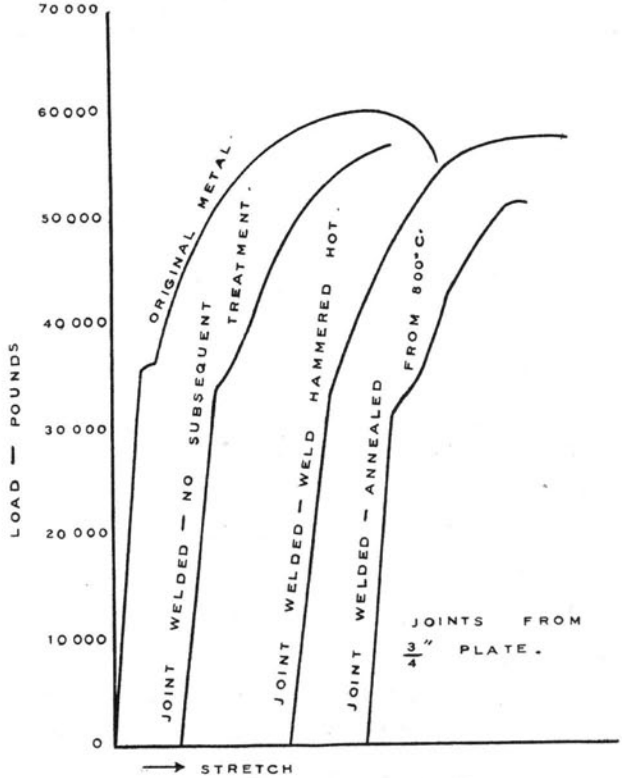

FIG. 5. TYPICAL TENSION TEST DIAGRAMS

cause failure. At a in Fig. 9 the specimen commenced to fail; a crack appeared in the outer fibres and progressed rapidly across the specimen. The length, ba, is taken as a measure of the number of repetitions required to cause failure.

Fig. 6 shows in diagram the Hatt-Turner drop testing machine used for the impact tests. The weight, W, is let fall from a predetermined position (shown by the broken line), and as it falls, a pencil attached to it draws a diagram on the rotating drum, *D*. For free fall this diagram is a parabola as shown in the upper part of Fig. 7, which is a typical test diagram. In the position shown in Fig. 6, (by the solid lines), the falling weight strikes the bars, *BB*, and through them and the crosshead, *C*, tensile stress is set up in the test piece, *Sp*, sufficient to cause rupture. *O* in Fig. 7 corresponds to the location of the weight when striking the bars, *BB*, (Fig. 6) and the lower part of Fig. 7 shows the free fall after the specimen is ruptured. In rupturing the specimen kinetic energy is taken from the falling weight and its speed is reduced; after breaking the specimen another free fall takes place. Ordinates in Fig. 7 represent distance, and, since the drum revolves uniformly, abscissas represent time; hence, the slope of the diagram of Fig. 7 at any point gives a measure of the velocity of the falling weight at that point. The amount of energy absorbed in breaking the specimen can be determined if the velocities at two points in the fall, one before the weight stresses the specimen and one after rupture, are determined. In Fig. 7 let the first point be chosen at *a* and the second at *b*, and let the vertical distance from *a* to *b* be denoted by *h*. The velocity of the falling weight at *a* is given by the slope of the diagram at *a;* call this velocity V_a. Similarly determine v_b, the velocity at *b*. The kinetic energy of the falling weight is

$$\frac{1}{2}\,\frac{W}{g}\,V_a^2$$

in which *W* is the weight of the falling weight, and *g* is the acceleration due to gravity (32.2 ft. per sec. per sec.). If the weight had fallen freely to *b*, the kinetic energy at *b* would have been

$$\frac{1}{2}\,\frac{W}{g}\,V_a^2 + Wh,$$

but the velocity at *b* is actually v_b, and the kinetic energy in the falling weight at *b* is

$$\frac{1}{2}\,\frac{W}{g}\,V_b^2.$$

The energy which has been absorbed in breaking the test specimen is then

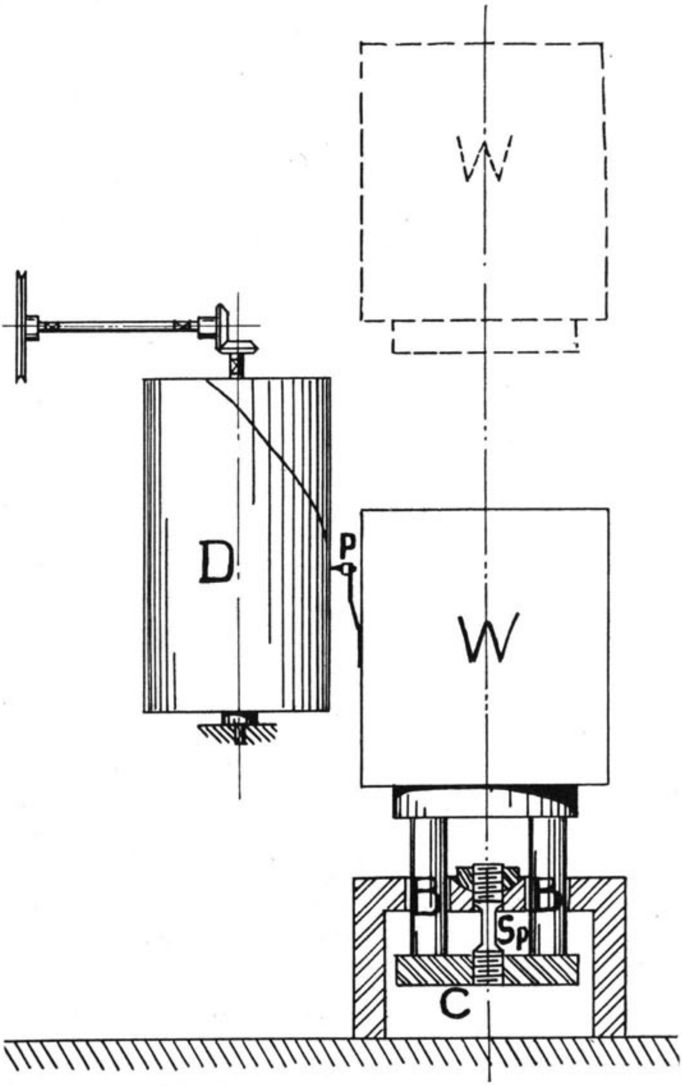

FIG. 6. DIAGRAM OF HATT-TURNER IMPACT TESTING MACHINE

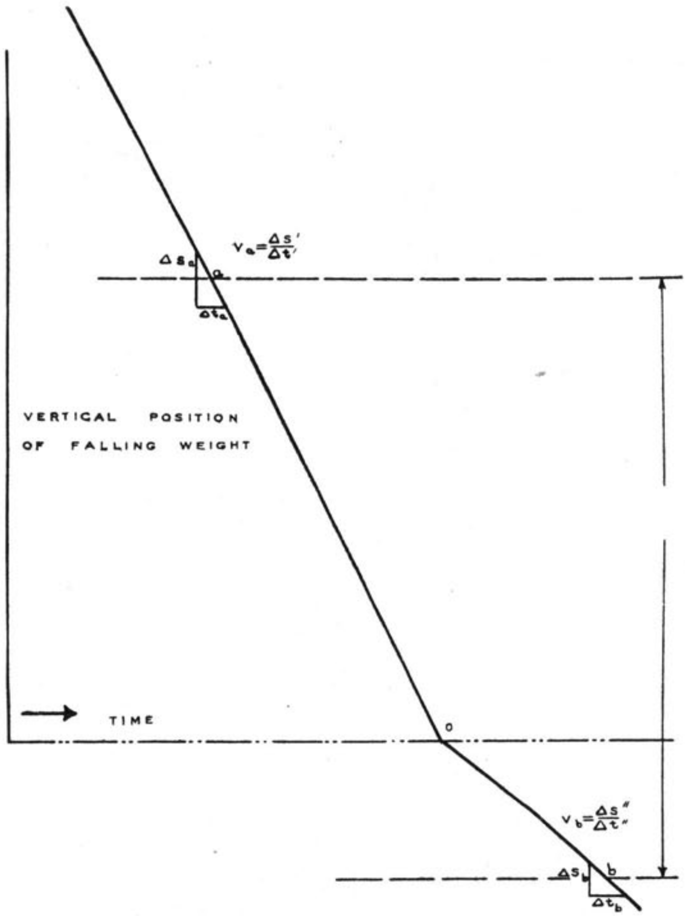

FIG. 7. TYPICAL DIAGRAM FROM HATT-TURNER IMPACT TESTING MACHINE

$$\left(\frac{1}{2}\ \frac{W}{g} V_a^2 + Wh\right) - \frac{1}{2}\ \frac{W}{g}\ V_b^2.$$

In this discussion, friction of the guides for the falling weight is neglected, as is the energy absorbed in vibrations of bars, and cross-heads, but these losses are not large, and since only a comparative test between welded and unwelded specimens is desired, the described method yields results sufficiently accurate.

5. *Data and Results of Tests.*—The prime object of these tests is to furnish a comparison of the strength of oxyacetylene welds in mild steel plates with the strength of the original plate. This ratio of strength will be called the *efficiency of a joint.* The efficiency of a joint may be computed by either of two methods:

(*a*) The strength of a test piece containing a welded joint is compared with the strength of a test piece of equal width cut from the original plate, with no allowance made for the additional thickness of the welded test piece due to the addition of filler material, or (*b*) the intensity of stress at yield point or rupture for joints and for plate material may be computed from the load and the dimensions of the cross section. The efficiency given by the first method will be called the *joint efficiency* and the efficiency given by the second method will be called the *efficiency of the material* in the joint. In general, joint efficiency is of more direct practical interest than is the efficiency of the material in the joint.

In tests for static strength and for strength under repeated stress both the values for joint efficiency and for efficiency of the material are given when it is possible. (Efficiency of material cannot be given if rupture occurs outside the weld.) In the impact tests the quantity measured was *energy* (measured in inch-pounds) rather than *intensity of stress* (measured in pounds per square inch), and only the joint efficiency was determined.

In connection with the discussion of efficiency it should be noted that the breaking of a test piece outside the weld does not necessarily mean that the efficiency of the joint is 100 per cent or more. The excessive heat involved in making an oxyacetylene weld may act to weaken the material near the joint so that the strength of the original piece is lessened and the failure will take place outside the welded joint.

The general results of the tests are given in Tables 1, 3, and 4. For the static tension tests and the impact tests, there are given for each thickness of plate: first, the results for the original material; and second, the results for the welded specimens expressed in terms of percentage of strength of the original material. The method of obtaining comparative results for the static tests and for the impact tests needs no explanation.

The method of obtaining comparative results for the repeated stress tests is somewhat complicated and will be given in detail. Table 2 gives the direct results of the repeated stress tests, the nominal stresses given in that table being the computed stress based on the thickness of the original plate. The actual stresses are based on the dimensions of the cross-section of the specimen at rupture.

It has been found* that for the range covered by these tests the relation between the computed fiber stress, S, in a specimen, and the number of repetitions, N, necessary to cause failure, may be represented with a good degree of accuracy by an equation of the form

$$S = \frac{B}{N^q} \text{ or } \log S = \log B - q \log N$$

in which B and N^q are experimentally determined constants. Plotted on logarithmic paper the graph of this equation is a straight line. The results of the repeated stress tests of oxyacetylene welded joints, when plotted on logarithmic paper, fell fairly closely along straight lines.

The test results for the specimens from each test panel were plotted on logarithmic paper and a straight line drawn to fit these results as closely as possible. The slopes of the lines for the results of all test strips were then averaged and for each test panel a line with the average slope was drawn according to the test results.

By means of this line with the average slope, the nominal stress, S, corresponding to failure at one thousand repetitions, was determined for each test panel and taken as an index of strength under

*Basquin, "The Exponential Law of Repeated Stress," Proc. A. S. T. M., 1910; Moore and Seely, "Failure of Materials under Repeated Stress," Proc. A. S. T. M., 1915; "Constants and Formulas for Repeated Stress Calculations," Proc. A. S. T. M., 1916.

TABLE 1

TENSION TESTS OF OXYACETYLENE WELDED JOINTS IN STEEL PLATES
All Values for Efficiency are given in Per Cent

I. PROPERTIES OF THE MATERIAL IN THE PLATES (SPECIMENS 1, 3, and 20)

Thickness of Plate	No. 10 Gauge	¼ Inch	½ Inch	1 Inch
Yield Point (lb. per sq. in.)	30 800	38 600	33 600	33 600
Ultimate (lb. per sq. in.)	47 000	55 400	57 100	57 700
Elongation in 8 in. (per cent)	10.0	28.2	27.5	31.6

II. EFFICIENCY OF THE JOINT BASED ON YIELD POINT

Material of plate, annealed from 800 degrees C.	82	87	89	90
Joint welded, no subsequent treatment	140	103	100	97
Joint welded, annealed from 800 degrees C.	107	84	92	81
Joint welded, quenched, annealed from 800 degrees C.	101	90	92	78
Joint welded, hammered while hot	128	109	101	104
Joint welded, hammered while hot, annealed from 800 degrees C.	106	80	95	94

III. EFFICIENCY OF THE MATERIAL IN THE JOINT BASED ON YIELD POINT

Material of plate, annealed from 800 degrees C.	82	87	89	90
Joint welded, no subsequent treatment	...	...	81	87
Joint welded, annealed from 800 degrees C.	...	...	81	74
Joint welded, quenched, annealed from 800 degrees C.	...	...	86	76
Joint welded, hammered while hot	...	...	87	98
Joint welded, hammered while hot, annealed from 800 degrees C.	...	...	86	84

IV. EFFICIENCY OF JOINT BASED ON THE ULTIMATE

Material of plate, annealed from 800 degrees C.	91	96	92	89
Joint welded, no subsequent treatment	114	101	97	79
Joint welded, annealed from 800 degrees C.	104	87	87	72
Joint welded, quenched, annealed from 800 degrees C.	103	95	83	79
Joint welded, hammered while hot	128	101	92	88
Joint welded, hammered while hot, annealed from 800 degrees C.	106	83	89	82

V. EFFICIENCY OF THE MATERIAL IN THE JOINT BASED ON THE ULTIMATE

Material of plate, annealed from 800 degrees C.	91	96	92	89
Joint welded, no subsequent treatment	...	73*	77	71
Joint welded, annealed from 800 degrees C.	...	...	75	65
Joint welded, quenched, annealed from 800 degrees C.	...	...	78	76
Joint welded, hammered while hot	...	...	77	80
Joint welded, hammered while hot, annealed from 800 degrees C.	...	...	76	74

*Each value is the average result from three tests except the value starred, which is the average result of two tests.

Table 2

Repeated Stress Tests of Oxyacetylene Welded Joints in Steel Plates

The Repeated Stress Tests were made in an Upton-Lewis Endurance Testing Machine with a Speed of 250 r.p.m.

Specimen	Thickness of Plate, Inches	Computed Fiber Stress Lb. per Sq. In.		Repetitions before Failure
		Nominal	Actual	
Material in Plate	No. 10 Gauge	45 000	44 200	13 200
		25 100	25 700	65 600
		30 600	29 100	11 400
		55 600	56 600	3 200
		32 400	32 600	33 800
		29 400	28 300	35 600
	¼	42 600	47 000	3 470
		58 200	59 000	4 120
		42 200	40 600	9 200
		35 100	34 300	62 900
	½	58 800	52 200	1 000
		36 000	32 100	34 000
	¾	42 300	40 500	9 200
		33 400	32 100	88 000
		48 400	47 000	4 800
	1	37 400	38 100	7 000
		26 100	26 100	64 700
		36 800	32 700	15 600
Material in Plate Annealed from 800 degrees C.	No. 10 Gauge	29 400	28 300	15 900
		29 000	28 200	34 800
		32 500	35 300	3 850
		26 200	26 200	75 500
	¼	30 100	28 300	72 500
		50 900	47 800	2 470
		47 600	46 100	1 640
		31 800	30 800	48 600
	½	45 700	40 600	2 800
		29 300	29 700	25 600
		50 800	51 300	680
		39 700	39 300	3 770
	¾	33 000	31 700	88 000
		34 400	28 700	19 400
		57 600	48 200	700
	1	37 400	38 100	7 000
		26 100	26 100	64 700
		36 800	37 200	15 600
Joint Welded, no subsequent treatment	No. 10 Gauge	51 000	48 800	4 100
		29 400	27 800	38 300
		32 100	28 700	156 500
	¼	70 000	61 800	2 730
		50 800	58 500	2 790
		33 100	26 750	239 000
		52 000	48 200	13 500
	½	36 200	30 900	22 800
		44 000	35 500	13 200
		67 300	48 500	700
	¾	34 400	28 700	19 400
		57 600	48 200	700
	1	45 000	40 300	1 400
		38 000	34 900	7 500
		27 800	25 300	47 400
Joint Welded, Annealed from 800 degrees C.	No. 10 Gauge	46 500	39 300	3 940
		35 500	32 000	29 400
		40 500	31 600	4 100
	¼	44 200	37 800	11 700
		36 600	32 200	78 500
		60 300	51 700	1 750
	½	50 600	34 900	2 250
		33 700	28 700	21 800
		58 100	42 100	800
	¾	49 700	43 200	800
		37 400	33 100	2 550
	1	44 000	40 000	5 350
		34 600	30 100	10 600
		26 100	23 700	13 800
Joint Welded, quenched, Annealed from 800 degrees C.	No. 10 Gauge	26 100	21 800	157 500
		34 600	33 500	9 500
		38 300	37 700	6 300
	¼	55 100	48 300	750
		32 400	24 200	13 600
		39 100	35 800	34 000
		46 800	46 000	6 250
	½	52 400	38 700	1 550
		33 300	26 700	32 500
		35 700	24 900	61 000
	¾	42 200	34 700	3 250
		50 900	42 500	950
	1	44 100	39 700	2 850
		36 500	32 900	6 800
		25 000	23 400	19 200
Joint Welded, Hammered while hot	No. 10 Gauge	60 800	58 400	5 570
		48 700	44 250	11 400
		38 400	36 300	76 500
	¼	59 300	60 200	1 100
		40 700	38 800	10 000
		62 800	32 600	107 500
	¾	36 800	29 600	23 500
	1	48 300	43 900	2 250
		38 100	34 600	15 800
		27 200	25 200	45 600
Joint Welded, Hammered while hot, Annealed from 800 degrees C.	No. 10 Gauge	46 500	38 700	5 000
		20 800	16 500	334 000
	¼	55 200	52 200	1 400
		32 800	25 100	84 000
		37 500	34 900	12 600
	½	36 400	26 800	52 000
		55 300	42 300	2 000
		42 200	32 400	7 500
	¾	42 100	36 400	6 500
		36 400	32 200	6 500
	1	43 700	39 800	3 550
		34 200	32 600	11 400
		28 500	26 900	16 900

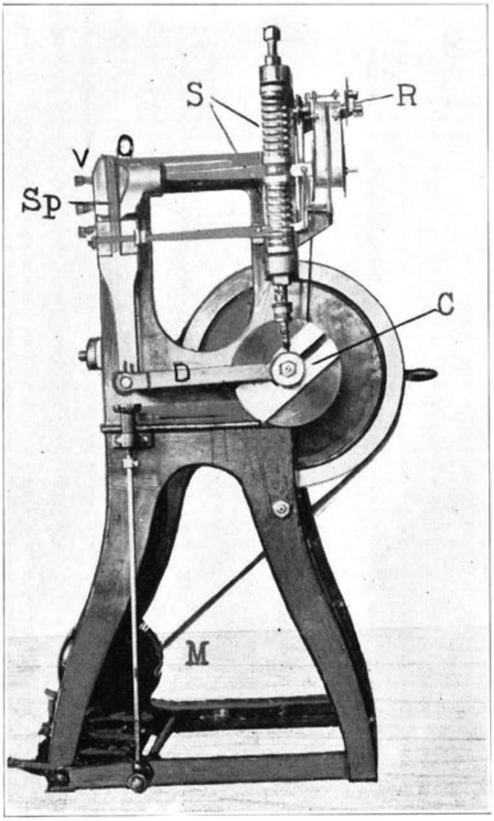

FIG. 8. UPTON-LEWIS MACHINE

SPECIMEN FROM 1″ PLATE; WELDED, HAMMERED HOT, UNNEALED FROM 800°C

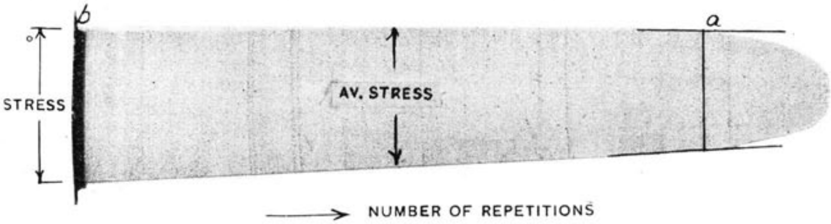

FIG. 9. TYPICAL DIAGRAM FROM UPTON-LEWIS MACHINE

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TABLE 3

SUMMARY OF RESULTS OF REPEATED STRESS TESTS OF OXYACETYLENE WELDED JOINTS IN STEEL PLATES

All Efficiencies are given in Per Cent

I. EFFICIENCY OF THE JOINTS

Thickness of plate	No. 10 gauge	¼ inch	½ inch	¾ inch	1 inch
Material in plate	100	100	100	100	100
Material in plate, annealed from 800 degrees C.	75	91	84	100	94
Joint welded, no subsequent treatment	100	125	102	88	96
Joint welded, annealed from 800 degrees C.	94	110	93	74	94
Joint welded, quenched, annealed from 800 degrees C.	90	95	94	84	86
Joint welded, hammered while hot	121	102	117	106	98
Joint welded, hammered while hot, annealed from 800 degrees C.	85	97	102	90	92

II. EFFICIENCY OF THE MATERIAL IN THE JOINTS

Thickness of plate	No. 10 gauge	¼ inch	½ inch	¾ inch	1 inch
Material in plate	100	100	100	100	100
Material in plate, annealed from 800 degrees C.	82	86	90	100	94
Joint welded, no subsequent treatment	98	108	92	76	86
Joint welded, annealed from 800 degrees C.	87	94	80	70	85
Joint welded, quenched, annealed from 800 degrees C.	84	82	81	71	79
Joint welded, hammered while hot	122	97	98	86	89
Joint welded, hammered while hot, annealed from 800 degrees C.	76	85	85	84	86

TABLE 4

RESULT OF IMPACT TENSION TESTS OF OXYACETYLENE WELDED JOINTS IN STEEL PLATES

All Efficiencies are given in Per Cent

I. PROPERTIES OF MATERIAL IN PLATE

Thickness of plate	½ Inch	¾ Inch	1 Inch
Energy required to cause rupture of specimen* (foot pounds)	511	1120†	1215

II. EFFICIENCY OF THE JOINTS

Thickness of plate	½ Inch	¾ Inch	1 Inch
Material in plate, annealed from 800 degrees C.	97	93	89
Joint welded, no subsequent treatment	64	37	53
Joint welded, annealed from 800 degrees C.	66	37	35
Joint welded, quenched, annealed from 800 degrees C.	88	44	32
Joint welded, hammered while hot	89	48	58
Joint welded, hammered while hot, annealed from 800 degrees C.	72	41	53

*See Fig. 4.

†Estimated from tests of annealed joints.

repeated stress. Any number of repetitions could have been chosen as the index number; one thousand was convenient. The stress, S_p, corresponding to failure at one thousand repetitions, was determined for the plate material, and the ratio $S:S_p$ was taken as the efficiency of the test joint. If S was computed on the basis of nominal dimensions of cross-section, $S:S_p$ gives the joint efficiency under repeated stress. If S was computed on the basis of actual dimensions of cross section, $S:S_p$ gives the efficiency of the material under repeated stress.

6. *Summary.*—A few general comments on the test results are given in conclusion.

These tests were made on joints welded by skilled workmen in a shop especially fitted for oxyacetylene welding. They should not be considered as indicative of the strength of welds made in repair shops, or of welds made by workmen without special training in the use of the oxyacetylene torch.

For joints made with no subsequent treatment after welding, the joint efficiency for static tension was found to be about 100 per cent for plates ½ in. thickness or less, and to decrease for thicker plates.

For static tension tests the efficiency of the material in the joints welded with no subsequent treatment is not greater than 75 per cent.* The joints were strengthened by working the metal after welding and were weakened by annealing at 800 degrees C.

The results of the repeated stress tests give an index of the endurance qualities of the joints, and they follow in a general way the results of the static tests.

For repeated stress tests the joint efficiency seems to be about 100 per cent for plates ½ in. or less in thickness, while the efficiency of the material in the joint is somewhat less. Hammering or drawing the weld while hot increases the strength, and annealing from 800 degrees C. lowers it.

For static tests and for repeated stress tests, the joint efficiency sometimes reaches 100 per cent; the efficiency of the material in the joint is always less. This indicates the necessity of building up the weld to a thickness greater than that of the plate.

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*Bulletin 45 of the Engineering Experiment Station of the University of Illinois, by H. L. Whittemore, showed efficiencies of material in the joints of 75-85 per cent after the operator had become proficient.

The impact tests show that oxyacetylene welded joints are decidedly weaker under shock than is the original material; for joints welded with no subsequent treatment, the strength under impact seems to be about half that of the material.

If the welded joint is worked while hot the impact-resisting qualities are slightly improved, though this does not make the joint equal to the original material in impact-resisting qualities. Annealing from 800 degrees C. seems to have very little effect on the impact-resisting qualities.

In general, the test results tend to increase confidence in the static strength and in the strength under repeated stress of carefully made oxyacetylene welded joints in mild steel plates.

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PUBLICATIONS OF THE ENGINEERING EXPERIMENT STATION

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Circular No. 1. High-Speed Tool Steels, by L. P. Breckenridge. 1905. *None available.*

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